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Drainage characteristics of TOLEDO and HOYTVILLE SOILS

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DRAINAGE CHARACTERISTICS OF TOLEDO AND HOYTVILLE SOILS

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INTRODUCTION

The soils in Ohio which require drainage are either high in clay or contain layers which are slowly permeable because of structural characteristics. Water moves through them very slowly, resulting in saturated soils or surface ponding. The major drainage problems are concentrated in the lakebed area of northwestern Ohio, although extensive areas needing drainage are also found in the southwest, west central, and northeast parts of the state. Tile drainage is practiced extensively in the lakebed area of Ohio.

There are two important soil properties which affect tile drainage: the hydraulic conductivity and drainable porosity. Of these two properties it is generally agreed that conductivity is the more valuable for predicting the efficiency of depth and spacing designs. Conductivity measurements are variable, however, and a good correlation between field estimates of this property and tile-drainage performance has not been realized. For this reason, there is a need for evaluating tile drainage performance under field conditions for some representative soils which require artificial drainage.

In this investigation, small land areas (about one-half acre) have been utilized to study the drainage characteristics of Toledo and Hoytville soils. Both are fine textured Humic Gley soils that are found in appreciable acreages in the lakebed area of northwestern Ohio and should be representative of the poorly-drained clay soils which require tile drainage. A portion of these data have been reported in an earlier publication (8).

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EXPERIMENTAL PROCEDURE

Studies in Untiled Toledo Soil. An area approximately 50 by 50 feet was selected for studies in untiled Toledo soil. The experimental area was in bluegrass pasture. Though the site was untiled, there was an open ditch 150 feet from the site. Four ¾-inch, solid-wall pipes (piezometric tubes) were installed at each of five soil depths to observe fluctuations in hydraulic head under natural precipitation. The pipes were installed in four locations, each location containing one pipe each which terminated at the 8-, 15-, 24-, 36-, and 60-inch depths. The four locations were the corners of a square with a side length of 50 feet. The water levels in the pipes were recorded approximately 3 times per week for four months.

Studies in Tiled Toledo and Hoytville Soil. An area of approximately 120 by 120 feet was selected for investigations at tile drained sites on Hoytville and Toledo soils (see figure 1). A water table (WT) was established in the soil by applying water from an adjacent well with six sprinkler nozzles. The application rate was approximately 0.13 inches of water an hour, and water was applied so that 100 percent overlap occurred between sprinklers. Irrigation was continued until water began to pool on the surface of the experimental area, at which time the WT levels were measured in the perforated pipes located between and also directly above the tile lines. A WT was established near the ground surface on four occasions, and the water levels were recorded during WT subsidence. Changes of 0.1 to 0.3 feet in the water level in the tubes were measured until the WT subsided below tile depths or until rainfall altered the water level. Soil temperatures at the 12-inch depth averaged 20° C during the study at these two locations.

Soil samples for moisture content analysis were taken midway between the tile lines at depth intervals of 6 inches. Moisture contents were determined gravimetrically and reported on a dry weight basis. Six soil cores were taken from each of the soil horizons for density, porosity, and mechanical analyses. The monoliths were taken with a cylindrical sampler which had an inside diameter of 3 inches and a length of the same dimension. Bulk densities were calculated as the ratio of oven-dry soil weight to its undisturbed volume at the time of sampling. The 60 cm. porosity was calculated as the percentage by volume of pores drained with a suction of 60 cm. from the initially-saturated soil monoliths. Sand content was determined by sieving. Silt and clay contents were determined by the pipet method. Hydraulic

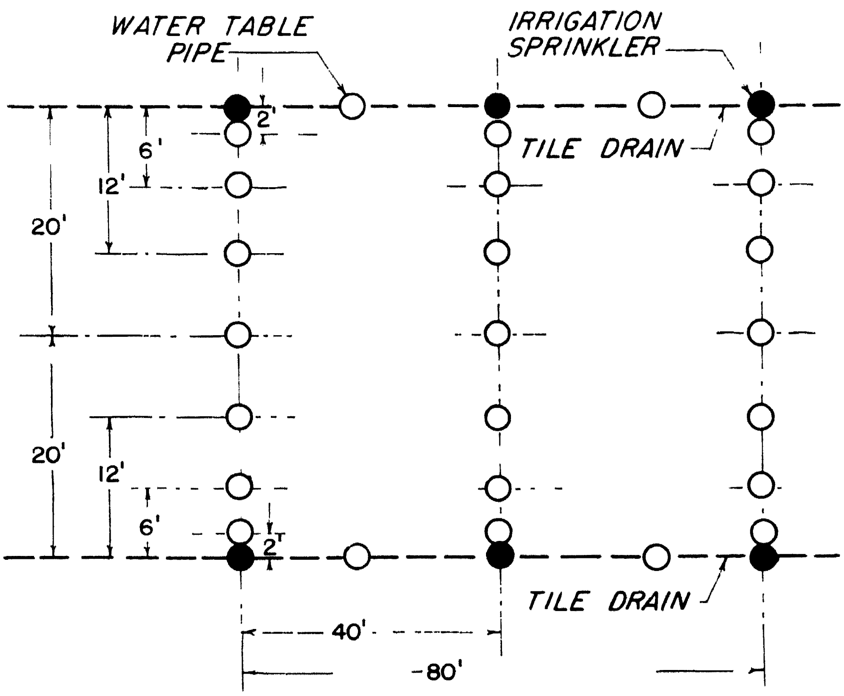

Fig. 1.—Schematic diagram of the experimental area and the facilities utilized in studying water table drawdown by tile drains in Toledo and Hoytville soils.

conductivities were estimated by the criteria of O'Neal (7). These criteria are based on an empirical relationship between conductivities of soil cores and the textural and structural characteristics of the soil.

Water table (WT) levels were measured in ¾-inch perforated pipes (sometimes called observation wells), the lower end of the pipes terminating 5 feet below the ground surface. The WT was measured to the nearest 0.05 feet with a calibrated tygon tubing. This was done by blowing into the tube as it was lowered into the pipe. When bubbling was first heard the tube had just reached the water level, and the depth of the tygon tube below the top of the pipe was recorded. From this value the distance between the ground and the upper end of the pipe was subtracted to yield the WT depth.

The principle involved in these measurements is that water moves into or from the perforated pipe until the water level in the pipe is the same as in the soil. The water level in the pipe represents a surface at which the hydrostatic pressure is zero. Since the WT is defined as the surface of zero hydrostatic pressure, the water level in the pipe approximates the soil depth at which a WT exists.

Hydraulic head measurements were made by measuring the water level in solid-wall pipes (often called piezometric tubes). These pipes were installed by first augering a hole whose diameter was approximately twice the outside diameter of the pipe, adding two inches of sand at the bottom of the augered hole, and then placing the lower end of the pipe about 1 inch into the sand. After placing a cloth above the sand to prevent its subsequent plugging, the hole was then filled to the ground surface with bentonite clay. The bentonite was used to prevent water movement to or from the pipe except at the bottom of the hole and to prevent vertical movement of water around the periphery of the pipe. The water level was measured in the same manner as described for the perforated pipe.

The height of the water level above the lower end of the solid wall pipe is equal to the hydrostatic pressure at the lower end. Since water in soil moves in response to both pressure and elevation differences, it is convenient to measure the water level from a particular reference level so that the measurement represents both of these components. This is done by measuring the vertical distance between the water level in the pipe and an arbitrarily-selected horizontal plane. Measurements recorded in this manner are called **hydraulic head potential** or more simply, **head.** An arbitrarily chosen reference plane can be used since water moves in response to differences in **head** and not as a result of absolute values. In this study, the ground level was selected as the reference plane, and the **head** ϕ is given by the following equation (3:p.44):

$$\phi = H - L = z \quad - - - - - - - \quad [1]$$

where H is the height of a column of water which yields the pressure of the water in the soil, L is the vertical distance from the ground surface to the lower end of the pipe, and z is the vertical distance from the ground surface to the water level in the pipe. The positive direction of z is upward.

I. STUDIES IN UNTILED TOLEDO SOIL

These studies were conducted during the winter and spring months of 1955. The major objective was to evaluate the hydraulic head and WT levels which occur in untiled Toledo soil under natural precipitation. The investigations were conducted near Sandusky at the North Central Substation, an experimental farm located in the glacial lakebed which covers extensive portions of Ohio, Indiana, and Michigan. The topography is nearly level, having an average slope of ½% in the experimental area. The experimental site is about ½ mile from Lake Erie, with a ground surface elevation from 3 to 5 feet above lake level. The soil is a very poorly drained Humic-Gley developed in lacustrine mixed clays and silts and is classified as Toledo silty clay loam.

TABLE 1.—Mechanical analysis, bulk density, 60 cm. porosity, and hydraulic conductivity of Toledo silty clay loam. North Central Substation, 1955

Horizon	Depth	Sand	Silt	Clay	Bulk Density	60 cm. Porosity	Hydraulic* Conductivity
	(In.)	(%)	(%)	(%)	(g./cc.)	(%)	(In./Hr.)
A	0-8	4.1	47.9	47.0	1.24	12.0	.90 to 2.18
B_{1g}	8-12	3.5	41.1	55.4	1.41	5.2	.06 to 0.2
B_{2g}	12-24	3.0	44.4	52.6	1.48	2.7	.06 to 0.2
B_{3g}	24-50	2.4	38.2	59.4	1.47	2.3	.06 to 0.2
C	50-66	1.6	51.5	46.9	1.45	----	.06 to 0.2

*Estimated by the criteria of O'Neal (7). The density and porosity values are averages of six samples.

Some physical properties of the soil at the experimental site are given in Table 1. There is very little sand in the profile. Clay contents are approximately 47% in the A and C horizons and are approximately 10% higher than this value in the B horizon. The volume of pore spaces drained at 60 cm. of water suction is relatively high in the A horizon but decreases rapidly in the B horizon (see figure 2). The estimated hydraulic conductivities are high in the shallow A horizon but much lower in the B and C horizons.

RESULTS AND DISCUSSION

The hydraulic head at the five soil depths are shown graphically in figure 3 for a few measurement dates during January through March. Rainfall is shown on a separate scale in the lower part of the figure. The hydraulic head is an average of those from four pipes. Its magnitude is closely related to current precipitation, high values being obtained shortly after significant amounts of rainfall. For any date, differences in hydraulic head as much as 3 inches were only obtained during early January, and it is quite probable that these differences are a result of disturbing the soil during installation of the pipes. The constancy of hydraulic head at the different soil depths indicates that only

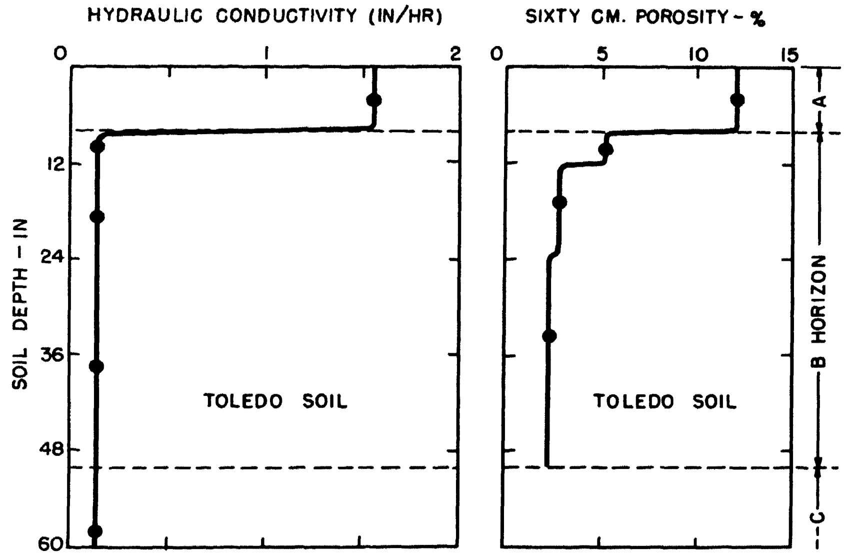

Fig. 2.—Hydraulic conductivity and sixty centimeter porosity of Toledo silty clay loam. Conductivities are based on soil morphological characteristics using the criteria of O'Neal (7).

small vertical gradients (if any) existed in the soil. Thus it is quite probable that little upward or downward flow of water occurred during these months.

Because of the nearly static conditions which are indicated by equal hydraulic head at the various soil depths, the WT depth is approximated

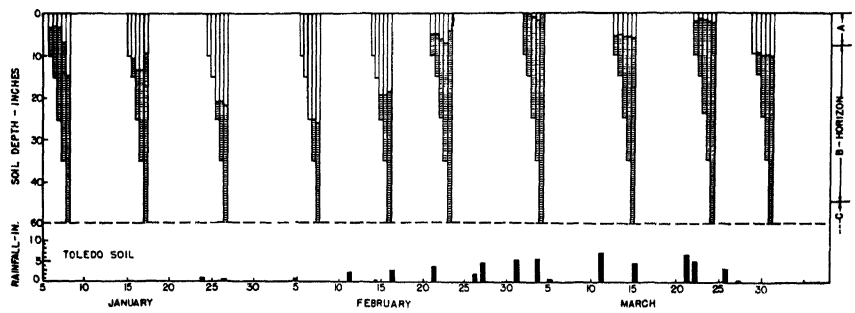

Fig. 3.—The effect of rainfall on hydraulic head at five soil depths in untiled Toledo silty clay loam. The relative hydraulic head is given by the water levels (indicated by meniscus) inside the five solid-walled pipes. The date shown directly below the pipe at 60 inches corresponds to the time at which the measurements were recorded. The transitions of the A, B, and C horizons are shown on the right. North Central Substation, 1955.

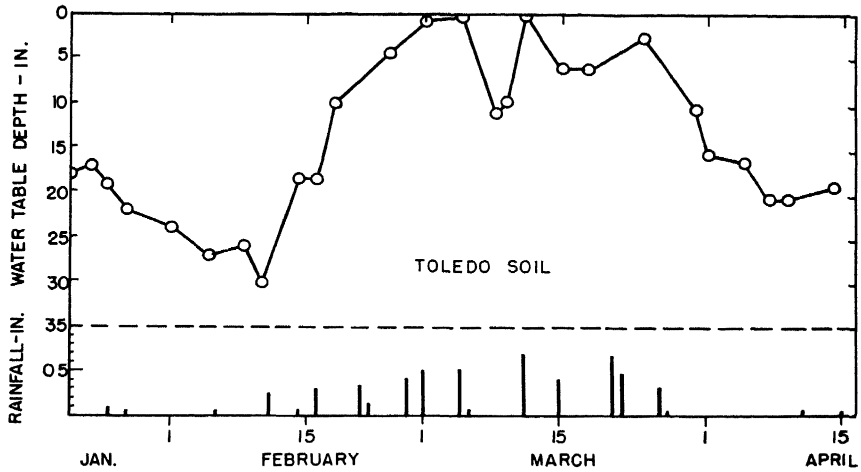

Fig. 4.—The effect of winter rainfall on water table depths in untiled Toledo silty clay loam. North Central Substation, 1955.

by the head measurement. Hence, the average water level at the five soil depths could also be used to represent the WT at the numerous dates at which water levels were recorded (see figure 4). Because of the low rainfall in late January and early February, the WT dropped slowly to a minimum depth of 32 inches on February 10. The subsidence could be due to water losses by deep seepage, however, the small hydraulic gradients which existed suggest that such losses are quite small. Another possibility is that the WT subsided because of greater moisture retention in the unsaturated soil as the soil temperatures decreased. A third possibility is that the WT subsided because of slow wetting of soil aggregates. At any rate, the experimental data shed little light on the importance of the different factors which resulted in WT subsidence.

The WT rose rapidly as a result of rains in late February and was at the ground surface on at least two occasions in March. Further subsidence occurred in early April, and this subsidence was most probably caused by higher evapotranspiration rates. These results are indicative of the high WT conditions which are found in Toledo soil without adequate drainage facilities.

II. STUDIES IN TILE DRAINED SOILS

A. TOLEDO SOIL

This study was also conducted at the North Central Substation but on an adjacent tile-drained site. The site characteristics were similar to that reported in the previous section. Seven years previous to the study, 4-inch diameter tile drains had been installed at 40-foot spacings and at an average depth of 30 inches. A third-year stand of alfalfa was in the experimental area. Prior to the first irrigation, wheat straw was spread over the area to reduce evapotranspiration.

RESULTS AND DISCUSSION

Water Table Drawdown. The most complete drawdown data were obtained during the second and fourth drawdowns, and these findings are shown in figure 5. Only the WT positions on one side of the

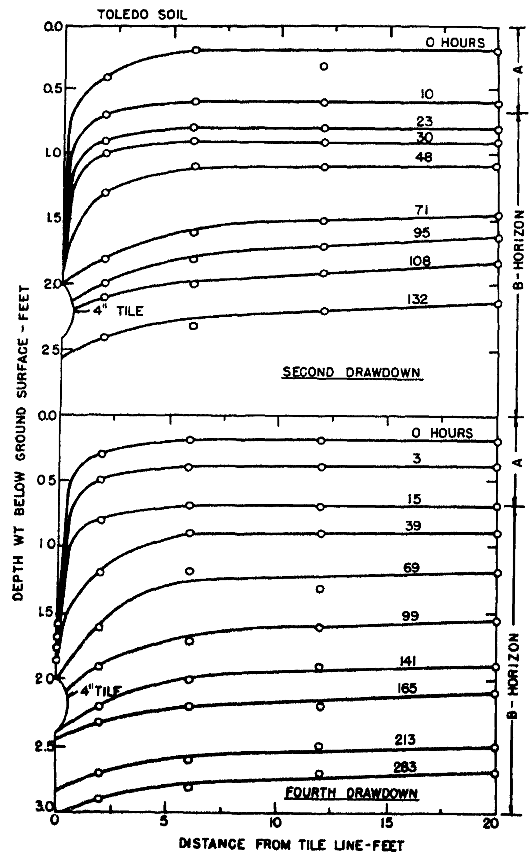

Fig. 5.—Water table (WT) depths at different horizontal distances from the tile lines during the second and fourth drawdown in Toledo silty clay loam. The numbers beside the curves give the time elapsed after irrigation had ceased.

tile line are presented since the drawdown surfaces were essentially identical on both sides. The WT surfaces are nearly horizontal at all times except in the region about 2 feet from the tile. In the four perforated pipes directly above the tile, the water level was only 3 to 5 inches above the drains during the first 21 hours of drawdown. After this time no water could be found in these pipes. Thus, it appears that drawdown might be described as rapid in the backfill but relatively slow and at an approximately uniform rate at other horizontal distances from the drain. The subsidence of the WT below tile depth undoubtedly results from evapotranspiration and deep seepage losses, the relative importance of each not being ascertainable from the data.

Drawdown at the Midplane. The WT depths at the midplane (20 feet) between tile lines is shown in figure 6 for various times during the second and fourth drawdowns. The rate of drawdown is slow, requiring two days to lower the water table to the 12-inch depth. The WT depths are linearly related (approximately) to the time elapsed following irrigation, although there appears to be a slight departure from linearity at the junction between the A and B horizons. It is known that drawdown is influenced by the soil hydraulic conductivity and the drainable porosity, and the data in the last two columns of Table 1 indicate that both of these characteristics change abruptly at the transition between the A and B horizons. In comparison to the B horizon the A

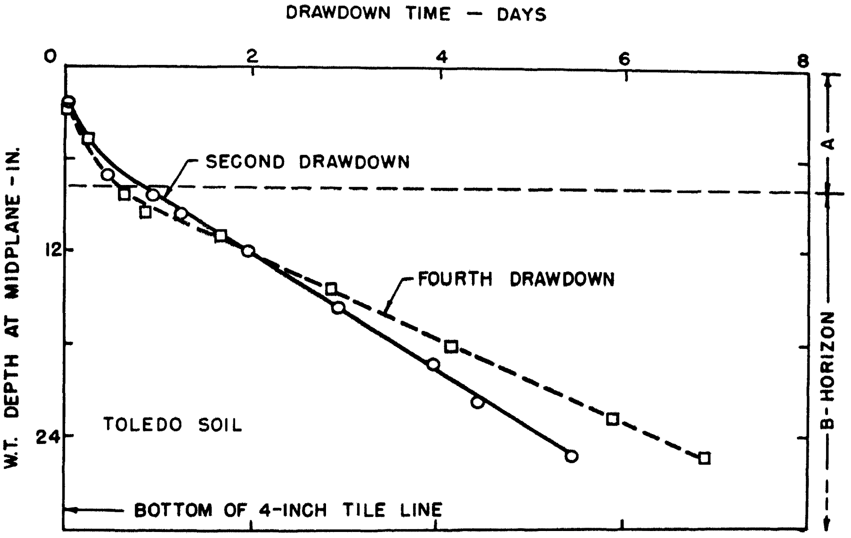

Fig. 6.—Water table (WT) depths at the midplane between tile lines during the second and fourth drawdowns in Toledo silty clay loam. The spacing between tile lines is 40 feet.

horizon is shallow, hence its high conductivity probably has little influence on the drawdown rate.

Soil Moisture Contents. Soil samples for moisture content analysis were taken at various dates during drawdown, and these results are shown graphically in figure 7 as a function of WT depth. The curves were visually fitted to the experimental points. Only the moisture contents of the A and B^{1g} horizons are shown since changes in moisture content at greater depths were too small to be detected (8). As the WT receded from the ground surface to tile depth, approximately 0.50 inches of water were drained from the entire A horizon. Under the same conditions only 0.10 inches were drained from the B^{1g} horizon. Thus it appears that tile drainage can bring about a significant reduction in moisture content in the A horizon but appreciably smaller quantities from the B.

These results are in qualitative agreement with the porosity data shown in figure 2; however, the 60 cm. porosity values overestimate the water removed by tile drainage. The reason for this discrepancy is that the highest moisture percentages obtained during field sampling were

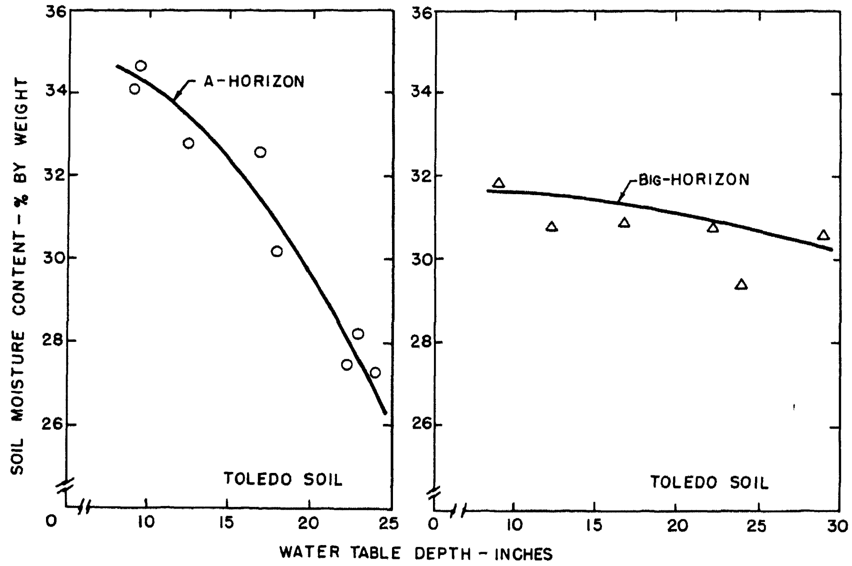

Fig. 7.—Soil moisture contents as a function of water table depths during the second and fourth drawdowns in Toledo silty clay loam. Soil samples were taken at the 6-inch depth in the A horizon (0-8 inches) and at the 12-inch depth in the B^{1g} horizon (8-12 inches). Each point represents the average moisture content in four soil samples.

significantly lower than the saturation percentages[2] estimated from the soil monolith data, particularly in the A horizon. For the A, B_{1d}, and B_{2d} horizons, the estimated saturation percentages were 43.1, 34.6, and 31.8, respectively; whereas, the highest moisture percentages found in these horizons by field sampling were 36.2, 32.0, and 30.9. For any particular horizon, difference between estimated and experimental values are probably a result of entrapped air in the field samples.

Water Removal Rates. Estimates were made of the rates at which water was removed from the upper part of the profile during drawdown. In making these estimates, it was assumed that significant amounts of water were drained only from the upper foot of the profile (see figure 7). The detailed procedure followed in making these estimates has been reported elsewhere (8). Briefly, differences in soil moisture contents at various drawdown times are used to estimate the amounts of water drained from the soil. The data reported in figure 7 were used for these analyses. The amount of water drained from the soil for any particular time interval is divided by this interval to yield the rate of water removal.

When the water removal rates were thus calculated and plotted as a function of WT depth at the midplane between tile lines, the relationship in figure 8 resulted. Because of the point scatter, a curve was not fitted to the experimental data, and these data are presented only to give the order of magnitude of water removal in this soil. As one can see from figure 8, the outflow rates ranged between 0.2 and 0.3 inches per day when the WT was in the plow layer.

B. HOYTVILLE SOIL

This investigation was conducted in 1956 at the Northwestern Substation experimental farm near Hoytville, Ohio. The soil at the site is a very poorly drained Humic Gley developed in clay till and is classified as Hoytville silty clay loam. Like the Toledo soil, the Hoytville series is found in the lakebed of Ohio. The topography is nearly level, having an average slope of ½% in the experimental area.

Some physical properties of the soil at the experimental site are given in table 2. Clay contents are approximately 10% less than in the Toledo soil, while the sand contents are 10-15% higher. The 60 cm.

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[2]Estimated values were calculated from the relationship $100\ (1/D_b - 1/D_p)$, where D_b and D_p are the bulk and particle soil densities, respectively. for the A, B_{1g}, and B_{2g} horizons.

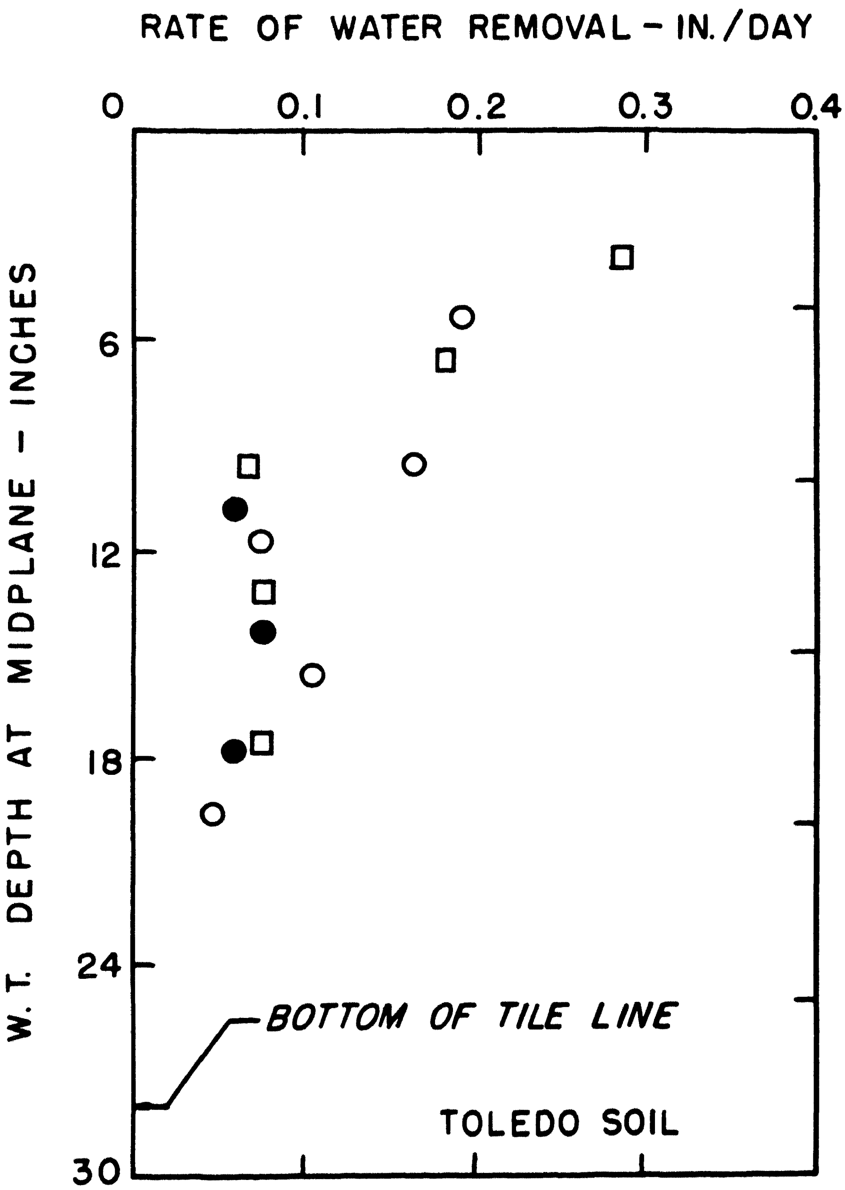

Fig. 8.—Estimated rates of water removal in Toledo silty clay loam as a function of water table (WT) depth at the midplane (20 feet) between tile lines. The experimental points shown by open circles, closed circles, and squares, respectively, represent data obtained during the second, third, and fourth drawdowns.

TABLE 2.—Mechanical analysis, bulk density, 60 cm. porosity and hydraulic conductivity of Hoytville silty clay loam. Northwestern Substation, 1956

Horizon	Depth	Sand	Silt	Clay	Bulk Density	60 cm. Porosity	Hydraulic* Conductivity
	(In.)	(%)	(%)	(%)	(g./cc.)	(%)	(In./Hr.)
A	0-9	20.6	41.8	37 6	1 29	10.5	.90 to 2.18
B_{21g}	9-18	16.0	37.1	46.9	1.45	4.5	.02 to 0.79
B_{22g}	18-27	15.9	35.8	48.3	1.54	3.1	.06 to 0.2
B_{3g}	27-42	17.2	37.0	45.8	1.60	3.7	.06 to 0.2
C	42-52	20.2	36.8	43.0	1.61	----	.06 to 0.2
C	52-108+	23.4	39 3	37.3	1.61	----	.01 to .04

*Estimated by the criteria of O'Neal (7): The density and porosity values are averages of six samples.

porosities are similar in magnitude to those found in Toledo (see figure 9). Hydraulic conductivities are higher in the upper portion of the Hoytville profile than in the Toledo but are of similar magnitude below 18 inches.

Five years previous to the study, 5-inch diameter tile drains had been installed at 40-foot spacing and at an average depth of 30 inches.

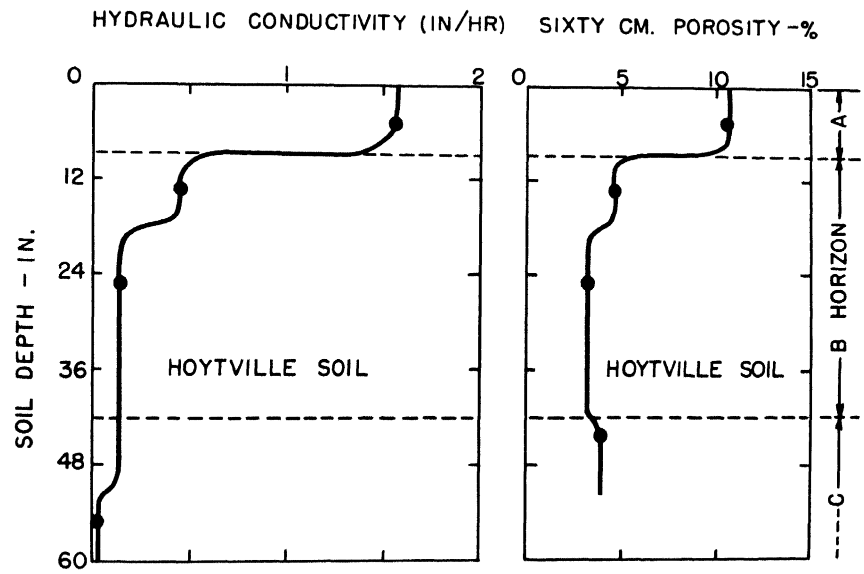

Fig. 9.—Hydraulic conductivity and sixty centimeter porosity of Hoytville silty clay loam. Conductivities are based on soil morphological characteristics using the criteria of O'Neal (7).

A second-year stand of alfalfa was in the experimental area. The overall procedure was similar to that followed at the Toledo site. The only exception was that one-third of the experimental area was covered with a large canvas to determine if evapotranspiration significantly reduced the moisture contents during the time in which WT levels were recorded. The WT levels in the covered and uncovered areas were similar, and these data are not reported separately.

RESULTS AND DISCUSSION

Water Table Drawdown. The most complete WT data were obtained during the third and fourth drawdowns, and these results are

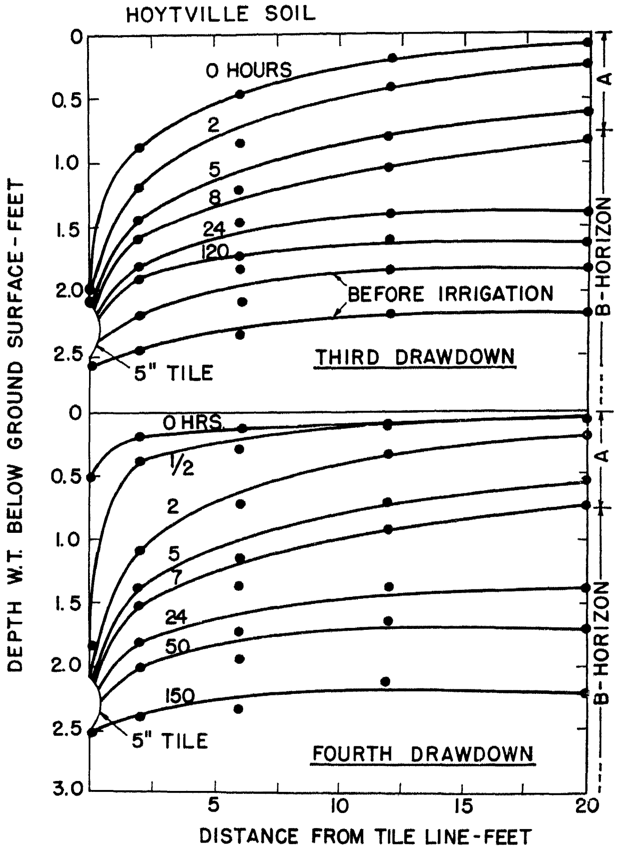

Fig. 10.—Water table (WT) positions in Hoytville soil during the third and fourth drawdowns. The numbers beside the curve give the time elapsed after irrigation had ceased. Prior to the fourth drawdown, the tile was temporarily sealed in order to raise the WT in the backfill.

presented in figure 10. The third drawdown was initiated on August 9, while the fourth drawdown started on August 21. The first and second drawdowns are not reported since they show essentially the same recession characteristics as the third and fourth and because of the greater probability that the soil was saturated prior to the third and fourth drawdowns. Following the presentation scheme used for the Toledo studies, only the WT positions on one side of the drain are shown.

The WT receded rapidly at small horizontal distances from the drain, and this finding is in good agreement with that reported earlier for the Toledo soil. The WT surfaces obtained during the third drawdown are almost identical to those resulting from the first and second drawdowns. In order to raise the WT in the backfill, the tile lines were temporarily sealed prior to the fourth drawdown. The high rate of drawdown in the backfill is indicated by the short time (one-half hour) required for the WT to subside from the 6-inch depth to tile depth. Once drawdown had occurred in the backfill, i.e. after the second hour of drawdown, the WT surfaces were similar in both shape and position for the two drawdowns.

The WT surfaces are relatively flat, although they show greater curvature than the ones reported for the Toledo soil. The reason for greater WT curvature in the Hoytville soil than in the Toledo is not apparent from the experimental data. It can be shown by controlled

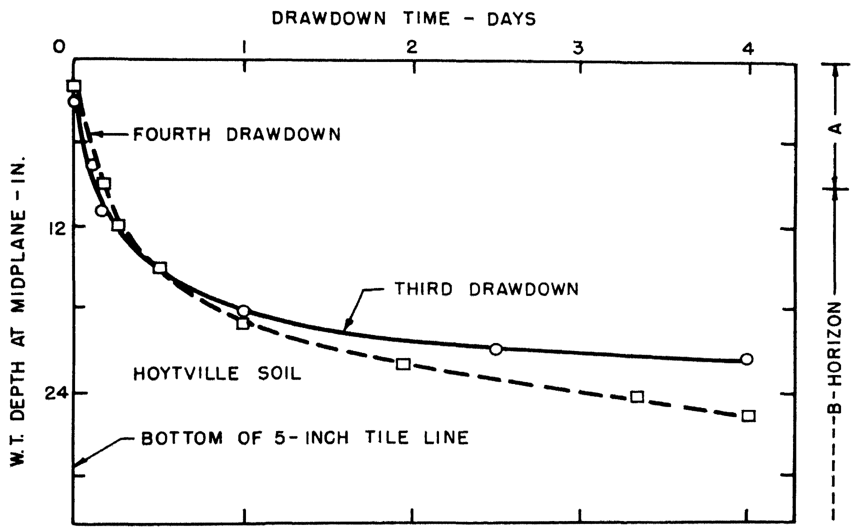

Fig. 11.—Water table (WT) depths at the midplane (20 feet) between tile lines during the third and fourth drawdowns in Hoytville silty clay loam.

drainage studies that the relationship between drainable pore space and water table depth affects the WT shape (9). The soil moisture data were not sufficiently accurate, however, to evaluate this effect. Actually, the WT positions obtained in both the Hoytville and Toledo soil are more horizontal than first apparent in figures 5 and 10 because of the exaggerated vertical scale.

Drawdown at the Midplane. The WT depths at the midplane (20 feet) between tile lines is shown in figure 11 for the third and fourth drawdowns. The rate of drawdown was quite rapid, particularly during the first few hours. After the WT subsided to approximately the 18-inch depth, the rate of drawdown was much slower. The agreement between the two curves was very good during the first 24 hours although some departure can be noted after the first day. This departure may be the cumulative effect of a slightly greater evapotranspiration during the fourth drawdown, resulting in a faster drawdown rate.

Soil Moisture Contents. Soil moisture contents are shown in figure 12 as a function of WT depth during the third and fourth drawdowns. Again only the moisture contents in the A and B^{21g} horizons are shown since no changes in soil moisture could be detected at greater depths. The curves were visually fitted to the experimental points. As the WT receded from the ground surface to the 26-inch depth, the moisture content in the A horizon decreased from approximately 34 to 26%. This decrease represents a change in moisture content of 0.09 inches of water per inch depth of soil or a total decrease in the A horizon of 0.8 inches of water. There is little change in soil moisture in the B^{21g} horizon (9-18 inches) during drawdown as indicated by the small slope of the resulting curve.

As observed with the studies in Toledo soil, the field moisture percentages of the Hoytville soil were likewise significantly lower than those obtained by saturating the soil in the laboratory. For example, the saturation percentages of the A and B^{21g} horizons were 39.6 and 32.8%, respectively, while corresponding values of 34.0 and 28.0% were the highest ones obtained by field sampling.

Water Removal Rates. Following the procedure described earlier, the estimated rates of water removal by the tile were calculated for the third and fourth drawdowns. The data reported in figure 12 were used for these analyses. The estimated rates are shown in figure 13 as a function of the WT depth at the midplane. The curve drawn therein was visually fitted to the experimental points. While there is some scattering of experimental points, a linear relationship is suggested. The maximum rate of water removal is approximately 0.4 inches per day

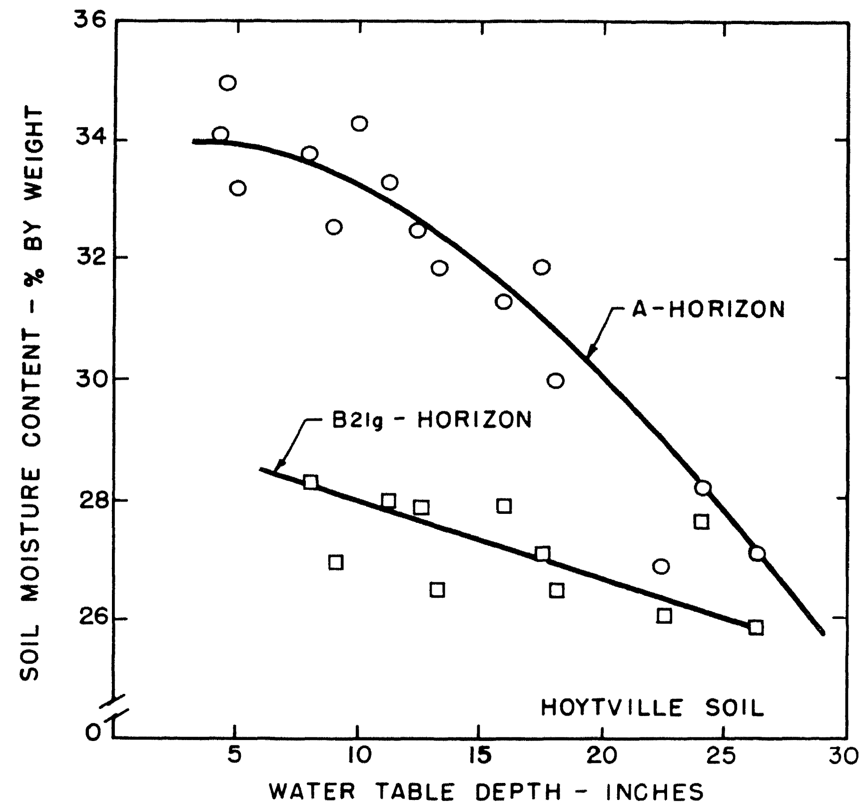

Fig. 12.—Soil moisture contents in Hoytville silty clay loam as a function of water table depth during the third and fourth drawdowns. Soil samples were taken at the 4-inch depth in the A horizon (0-9 inches) and at the 12-inch depth in the B_{21g} horizon (9-18 inches). Each point represents the average moisture content in four soil samples.

while a rate of zero is indicated by extrapolating the curve to drain depth. For comparable WT heights the rates of water removal are approximately one-third greater in the Hoytville than in the Toledo soil.

The linear relationship suggested by figure 13 is similar to that obtained at Tiffin when measured drain discharge rates were plotted against water-table depths at the midplane (2). Controlled tank drainage studies by Thiel and Taylor (9) also show a similar relationship for two sands which differed in conductivity and thickness of capillary fringe. They found that the same relationship was obtained for different drain depths. Luthin and Worstell (4) have also assembled field drainage data from many sources which show a linear relationship between drain outflow and water table heights at the midplane.

C. COMPARATIVE DRAINAGE IN HOYTVILLE AND TOLEDO

Drawdown at the Midplane. If drawdown in the Toledo soil is compared with that in the Hoytville (see figure 14), it will be noted that Hoytville has a faster drawdown rate during the first day. This finding

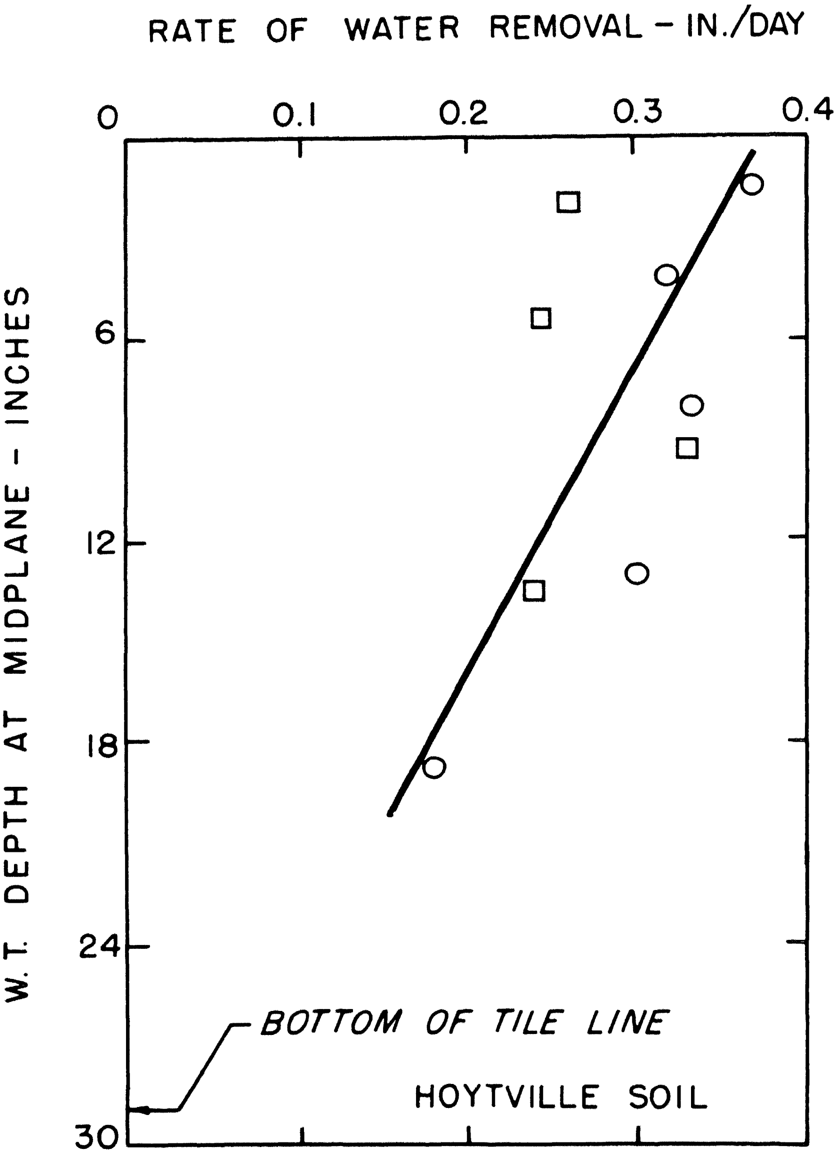

Fig. 13.—Rates of water removal in Hoytville silty clay loam as a function of water table (WT) depth at the midplane (20 feet) between tile lines. The circles and squares represent experimental points obtained during the third and fourth drawdowns, respectively.

is in qualitative agreement with drainage experience on these two soils. Based on the O'Neal criteria, conductivities are higher in the upper B horizon of the Hoytville soil than in the same horizon of Toledo soil. Thus the faster drawdown in the Hoytville may be due to its greater conductivity in the upper B horizon.

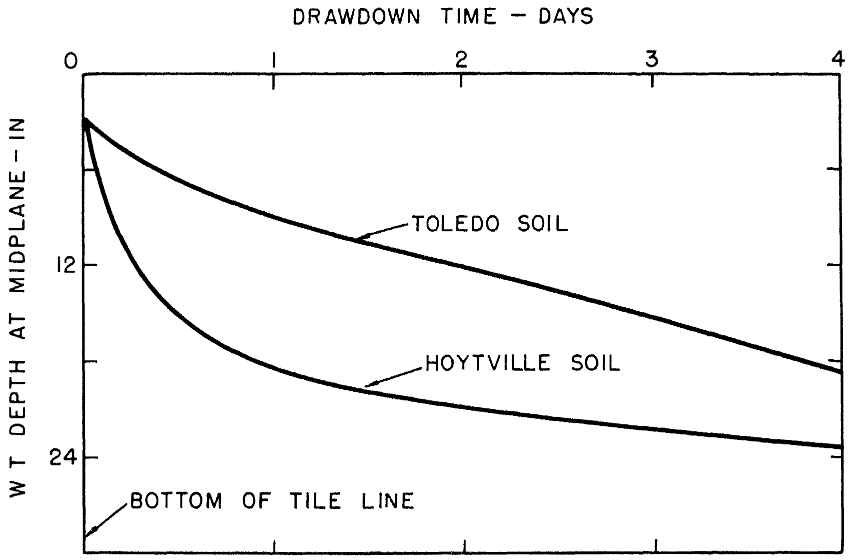

Fig. 14.—Water table (WT) depths at the midplane in Hoytville and Toledo soil during drawdown by tile drains. The WT positions are averages of these reported in figures 8 and 13, respectively, for the Toledo and Hoytville soils.

Hydraulic Conductivity. Early in the study, some evaluations were made of soil hydraulic conductivities by the auger hole method. The experimental values obtained by this technique on Hoytville soil were very erratic, and the data were not analyzed. The conductivities obtained in the B and C horizons of the Toledo soil were so small (about .005 inches per hour) that no attempt was made to incorporate these findings in this report (10).

In this study, an **equivalent conductivity k** was calculated by utilizing the rates of water removal shown in figures 8 and 13. As used herein, this conductivity is **equivalent** to that of a homogeneous soil which under comparable WT height at the midplane will yield the same inflow into an open drain as actually measured under field conditions. It was assumed in these analyses that a linear relationship exists between drain outflow and WT heights. Except for initial WT recession following surface ponding (1, 2, 9), this assumption has been supported by controlled experimental studies. We are not particularly concerned here with the exception, and will ignore it in these analyses.

The linear relationship assumed above has been expressed mathematically by Luthin (5) in equation 2.

$$Q = cky \quad - - - - - - - - - \quad [2]$$

where Q is the drain flow in cubic feet per foot length of drain per day, c is a constant, k is the hydraulic conductivity in feet per day, and y is the height of the WT at the midplane in feet. The horizontal plane passing through the drain center is at $y = 0$. If one knows the magnitude of the constant c, k can be calculated from experimental values of Q and y. By utilizing an electrical resistance network, the constant c was obtained by solving the analogous case for steady state rainfall in equilibrium with flow into an open drain (3:p.113-138). The drain diameter, spacing, and depth were those used in the field studies. An impermeable layer was imposed at the upper boundary of the C horizon.

The equation for total current flow I through the network for the analogous rainfall case is given by equation 3.

$$I = c\,\sigma\,V = cAy/R \quad - - - - - \quad [3]$$

In equation 3, σ is the electrical conductivity, V is the voltage applied at y, and R is the "characteristic resistance" of the network whose reciprocal is equal to σ. The constant A is defined by $V = A(y\text{-}r)$, where r is the drain radius. A voltage potential of zero (ground) is applied at the drain. Thus c is given by equation 4.

$$c = IR/Ay \quad - - - - - - - - - \quad [4]$$

Using the magnitude of c as given by equation 4, equation 2 was used to solve for k by using the water removal rates at known WT heights y as shown in figures 8 and 13. The value of Q was given by multiplying the water removal rates by the tile line spacing, changing all length units to feet. The resulting value of k are reported below, along with a previously-determined value for Nappanee soil at the Tiffin Drainage Experiment.

Soil	**Equivalent conductivities k**
Toledo	0.43 inches per hour
Hoytville	0.82 inches per hour
Nappanee (2)	0.88 inches per hour

The equivalent conductivities exceed those predicted by the O'Neal method by a factor of two or more. One might recall here that the O'Neal method is based on water transmission through soil cores. The discrepancy is much greater when these values are compared with the auger hole method. For example, the auger hole method (8) predicts only 0.005 inches per hour! The agreement between equivalent conductivities in the Hoytville and Nappanee is encouraging since drawdown rates are quite similar for these two soils (2).

Practical Consideration. Considering the small amount of water which is drained from the B horizon in these soils, one might conclude that tile drainage does not greatly improve aeration below the 12-inch soil depth. Since these soils are known to be productive for agronomic crops when tile drainage is practiced, these findings further suggest (6) that the major criterion in drainage of agricultural land should be based on the degree of drainage in the top foot of soil. Because of the low rates at which water is removed from the solum, it appears desirable to supplement underground drains on these soils with surface drainage.[3]

SUMMARY

The following conclusions can be drawn from these studies:

1. Water table recession by tile drains is quite rapid in the backfill and in the soil a few feet on either side of the backfill. This condition was found in both Toledo and Hoytville soil.
2. During WT recession, the WT surfaces are nearly flat except in and near the backfill.
3. During the first day of recession, the rate of drawdown in tiled Hoytville soil is approximately twice as fast as in tiled Toledo soil. The faster drawdown rate is attributed to the higher conductivity in the Hoytville soil.
4. The calculated rates of water removal by tile drains is one and a half times greater in Hoytville than in Toledo soil.
5. Significant changes in soil moisture content following saturation of tiled Toledo and Hoytville soil occur only in the A horizon, the horizon which coincides approximately with the plow layer.
6. Based on changes in moisture contents, the equivalent conductivity of Hoytville and Toledo soils was 0.82 and 0.43 inches per hour, respectively. These rates are two or three times greater than predicted by the auger hole method or by the criteria based on soil morphological characteristics.

[3]An experiment is now underway at the North Central Substation to evaluate both surface and subsurface drainage facilities.